California Advanced Reciprocating Internal Combustion Engines Collaborative

WORKSHOP PROCEEDINGS

California Energy Commission
July 10, 2001
at
Employment Development Department Auditorium
722 Capitol Mall
Sacramento, CA 95814

Background. On July 10, 2001 the California Energy Commission held a workshop at the Employment Development Department Auditorium in Sacramento, California to discuss issues related to the California Advanced Reciprocating Internal Combustion Engines (ARICE) Collaborative. Attendees included representatives from engine manufacturers, governmental agencies, (federal, state and local), the ARICE technologies R&D companies, national labs, utilities, power suppliers, fuel suppliers, end users, R&D sponsors, academia, and non governmental organizations. A list of the people who attended the workshop is attached. The purpose of the workshop was to inform the attendees of the ARICE program, inform the ARICE industry of current projects and technologies, and to obtain suggestions from potential program participants for structuring a successful RD&D program and CEC's upcoming ARICE solicitation. This document summarizes the key points covered at the workshop.

Presentations. The workshop began with a series of presentations from 8:00am to 1:00pm with a brief 15 minute break at 10:15 am. The presentations included speakers from four different panels: 1) Federal, State, and Local Organizations; 2) Engine Manufacturers; 3) National Labs and Universities; and 4) Private R&D, Fuels, Exhaust Treatment.

Panel I Federal, State, and Local Organizations

1. Terry Surles, *Deputy Director of Technology Systems, California Energy Commission (CEC)*
Public Interest Energy Research Program (PIER) – Overview and Objective

Terry Surles opened the workshop with an overview of the CEC's Public Interest Energy Research (PIER) Program. The vision statement of the PIER program reads as follows: "The future electrical system of California will provide a clean, abundant and affordable supply tailored to the needs of 'smart', efficient customers and will be the best in the nation." In the PIER program, attributes for addressing state issues include the following program integration: balanced technology portfolio, technology partnerships, and the focus on California. Terry stressed that technology partnerships are critical for the overall success of the program including collaborative funding, collaborative management, and the cooperation of other partnerships. The goal of the ARICE Program is: Can we develop substantively cleaner systems to add to our portfolio of modular energy technologies?

2. Avtar Bining, California Energy Commission (CEC)
California Advanced Reciprocating Internal Combustion Engines (ARICE) Collaborative – Purpose, Mission, Goals and Targets, and Action Plan

Avtar Bining discussed the overall purpose and objectives of the California ARICE Collaborative including the Purpose, Mission, Industry Issues and Concerns, Key Goals, Proposed R&D Projects, Industry Commitments, Current Status of Diesel and Natural Gas Engines and the One-Year Plan of the CEC in the ARICE program. The purpose of the California Advanced Reciprocating Internal Combustion Engines Collaborative is to take a leadership role in facilitating the research and development (R&D) of advanced reciprocating internal combustion engine (ARICE) systems that are super-efficient and ultra-clean for distributed, mobile, emergency and other power generation and stationary applications throughout California. The key goals of the ARICE program include: 1) Facilitating the research, development, demonstration, and commercialization of ARICE technologies by funding projects in partnership with stakeholders; 2) Facilitating the development of emission tests protocols that would establish common testing and evaluation criteria applicable to various parameters; 3) Implementing an independent and continuing inter-departmental policy in California to consider use of efficient and clean ARICE distributed power generation technologies in distributed generation, emergency power, and other stationary applications; and 4) Working with utilities and regulators to adopt policies that encourage the use of ARICE systems for power generation where size and suitability are compatible.

3. Joanna Livengood, *U.S. Department of Energy (DOE), Chicago Operations Office*

U.S. Department of Energy's Advanced Natural Gas Reciprocating Engine Program (ARES)

DOE is working to expand distributed energy options and is developing technologies for various power ranges including microturbines (<1MW), fuel cells (30-300kW), gas turbines (1-50MW), and reciprocating engines (<10MW). In 1999, DOE joined Southwest Research Institute (SWRI) commissioned by the Advanced Reciprocating Engines Systems (ARES) consortium to determine an advanced technology roadmap for reciprocating natural gas engines with a current 7 year program through 2006. The DOE program goals of a commercial natural gas engine by 2010 are: 1) High efficiency of at least 50%; 2) Environmental superiority - NO_x < 0.1 g/hp-hr; 3) Reduced cost of power; 4) Fuel flexibility; and 5) Reliability and maintainability. DOE's strategy is based on partnering with engine manufacturers and suppliers, national labs, and universities leveraging limited resources and reducing financial and technical risks. The engine manufacturers of the ARES Program are Caterpillar, Cummins, and Waukesha. The national labs of the ARES Program are SNL, ORNL, ANL, and NETL. The DOE/industry team recently visited six major national labs from April to June covering five technology categories: Combustion and ignition, After treatment, Air handling systems, Sensors and controls, and Friction reduction. The Industry team evaluated and prioritized 33 technology presentations and the top two technologies included After-treatment and Sensors and controls. DOE welcomes opportunities for collaborative research with CEC and the ARICE Program including benefits of decreasing the technology development timeline and leveraging of limited resources. DOE's proposal for the next steps to the ARICE program is: 1) Identifying areas of mutual interest and opportunities for cooperation; 2) Establishing communication mechanisms; and 3) Developing a working relationship for DOE-CEC-industry programs.

4. Tony Andreoni, California Air Resources Board (CARB)

An Overview of ARB'S Stationary Engine Emissions Control Plan

Tony Andreoni discussed the following issues: 1) The approach to controlling emissions (Non-regulatory – NOx and Regulatory – PM); 2) Typical NOx controls for SI engines; 3) Diesel RACT/BARCT (Reasonably Available Control Technology/Best Available Retrofit Control Technology); and 4) Diesel Risk Reduction Plan. In the RACT/BARCT Determination of the approach to controlling emissions, the districts are assisted with guidelines (not a lot of structure for the non-regulatory and more public input), existing engines are addressed (retrofit), and the emphasis is on NOx control. Regarding the Diesel PM (ATCMs), statewide control measures are implemented in developing new and existing engines. ARB provides guidelines to the Air Pollution control conflicts for controlling stationary source emissions. The typical NOx controls for rich burn SI engines include >90% NOx reduction for 3-Way Catalyst (NSCR) and >80% NOx reduction for prestratified charge. For the lean burn engine, there are >80% NOx reduction of low emission combustion and 80-90% NOx reduction for Selective Catalytic Reduction. The key to the Diesel RACT/BARCT is the coordinating efforts with the ATCMs for diesel-fueled engines. The goal of Diesel Risk Reduction Plan (Sept. 2000) is to reduce PM emissions from new and existing portable and stationary engines. Emission controls for diesel PM include: 1) Diesel Traps; 2) Oxidation catalysts for older engines; and 3) Other options of engine modifications, alternative diesel formulations and additives, alternative fuels, and electrification. The guidance for permitting new stationary diesel-fueled engines is separated into two categories - Emergency Standby and All other engines (with minimum technology to get below the standards and meet NOx limits). There are numerous demonstration programs in progress showing promising results and more testing is on the way also. Tony also suggested that toxics (diesel emissions) should be added into the ARICE mission statement along with criteria pollutants.

5. Martin Kay, South Coast Air Quality Management District (SCAQMD)

Air Quality Issues with Stationary Engines

SCAQMD, totaling 14 millions people and growing, includes Los Angeles County, Orange County, Riverside County, Non-Desert San Bernardino County, and Catalina Island. The SCAQMD once had the highest air pollution in the U.S., but levels have improved and the SCAQMD is currently number two in the nation, but still exceed the ozone and particulate matter standards. The attainment of standards is projected through 2010. The Best Available Control Technology (BACT or LAER) used by SCAQMD require clean fuels and lowest achievable emission limits. Emergency diesel engines were not used very much until last year when the brown outs began occurring, now the use of these engines have raised concern. The standards for the stationary and emergency IC engines were listed and the emission comparisons of gas turbines to engines, and diesel to natural gas were graphically presented. SCAQMD's concern with IC engines include: 1) IC engines have the highest emissions of all electric generators; 2) Health risk impact of diesel particulate (80% of cancer risk district was due to diesel); 3) Reliability – less monitoring, source testing and operator attention; and 4) Smaller generators may escape permitting requirements and emissions offsets.

Part II Engine Manufacturers

6. Vinod Duggal, Cummins Engine Company, Inc.

Cummins Advanced Reciprocating Engine Technology for California Distributed Generation

Cummins presence in today's California market includes over 240 MW sold and over 70 MW rented to the West Coast. With aftertreatment, all NOx emissions from engines can be drastically reduced. The efficiency levels of the current engines are Diesel (42%), Bi-Fuel (40%), Lean Burn (38-39%), and Stoichometric (32%). The major ongoing innovations at Cummins include the Advanced Lean Burn Gas project with the ARES Program including 1) Cost effective reduced emissions (after-treatment); 2) Improved efficiency (parasitic reduction and combustion system); 3) Extended maintenance intervals (ignition system solutions); and 4) Reduced initial cost (higher BMEP). The Westport Demo Genset, functional 2nd quarter 2001, is a 1.6MWe continuos, with onboard switchgear and grid paralleling controls, and can parallel grid connect or operate with load banks. Cummins is also working with Capstone on microturbines that will be demonstrated 4th quarter 2001. To reach the ultra-low emissions, SCR for NOx, DPF for PM, and Oxy Cat for CO and HC will all be necessary. Cummins believes there are a range of solutions to meet California's power generation needs and are dedicated to meeting future emissions and efficiency requirements. The improvements needed will take time and resources, and consortium efforts are essential to accelerate these developments. Lean burn natural gas offers the best trade-offs.

7. Jay A. Burnette, Goodrich Fairbanks Morse Engine

Status of Fairbanks Morse Engine Products for Stationary Power Generation

Goodrich Fairbanks Morse Engine works in the commercial end of the power generation industry (including some heavy industrial) and navy propulsion. The electric power generation is focused primarily in North America with some overseas projects. The engines manufactured include natural gas, medium speed that is continuous running and peaking engines (non-emergency). The three main products from Goodrich include the O-P Dual Fuel, FM/MAN 32/40 DG, and the Colt-Pielstick 18 V PC2.6 with emission levels of 1.0 g/bhp-hr NOx (uncontrolled), 0.1 g/bhp-hr NOx (w/SCR), and respected efficiencies of 41%, 42% and 43%. As the RPM drops, the efficiency goes up. The O-P Dual Engine with 1580-3165 kW capability, has a technical focus on environ-design dual fuel O-P, 7 second start-up, gas valves and heat recovery. The engines meet all the current requirements of the Bay Area AQMD, San Diego APCD, and South Coast AQMD. If all the heat were recovered in the engine at their Chula Vista, CA site, the efficiency would be approaching 90%. SCR is effective, but expensive accounting for 15-20% of the equipment cost in Chula Vista. The question remains, how do you control all the variables?

8. Martin L. Willi, Caterpillar Inc. (CAT)

Caterpillar's Perspective of Reciprocating Engine Technology: Current State-of-the-Art, Potential, Benefits, Technical Challenges

The GCM34 is the largest engine manufactured by CAT, and is the most efficient reciprocating engine of its size in the world today. The current diesel engines from CAT include power ranges of 1000-75000 kWe and 500-600 kWe, NOx emissions of 5-12 g/bhp-hr and 0.5-1 g/bhp-hr, and efficiency levels of 34-44% and 35-43%… a far cry from the proposed ARICE goals. The technologies needed include to reach these goals are heat recovery, exhaust after-treatment (low temperature capable catalysts and low sulfur diesel fuels), improved controls, In-cylinder NOx Control Technology (water injection technology and EGR pumps), and increased efficiency generators. There are multiple technical paths and a clear commercial need for improved reciprocating engine products.

9. Monte McCormick, Waukesha Engine Co.

Waukesha Engine Co. manufacturers natural gas engines – stoichiometric and lean burn. From 1985 to 2000, Waukesha has produced 62,000 units totaling over 2,900,000 kW worldwide – 76.5% power generation and the remaining 23.5% mechanical driven. Their ATGL product line carries efficiencies up to 42%, the VHP product line carries stoichiometric engines of 33% efficiency and 0.15 g/bhp-hr NOx (with catalyst) and lean burn engines of 35% efficiency with 0.7-1.25 g/bhp-hr NOx, and their VGF product line carries stoichiometric engines with 35% efficiency and Lean Burn with 39% efficiency. The technical challenges ahead are keeping in sync with the ARES program dealing with ignition systems, friction reduction (mechanical losses – must see improvement), sensors, and exhaust after-treatment. Engines without after-treatment will not reach the stated goals.

Panel III National Labs and Universities

10. Raj Sekar, *Argonne National Laboratory*

Internal Combustion Engine Research at Argonne National Laboratory

The focused mission for ANL is to develop technologies, not engines including the development of advanced technologies, experimental and analytical capabilities, and assisting in directing DOE and industry research. Industrial cogen research has continued for 12 years at ANL with oxygen-enriched diesel engine research and economic studies of distributed electrical power generation. The project with oxygen-enriched intake air lowering locomotive emissions needed 1) To “think out of the box”: 2) extensive analytical study proceeding engine experiments; and 3) extensive experimental data. Spark plug durability is a concern for current natural gas engines. X-rays open a new paradigm in engine research; x-rays penetrate the mist surrounding the spray area and reveal more realistic images. Near-frictionless carbon coatings are being tested also. Suggestions by ANL include 1) Laser-based ignition systems; 2) Engine-out emissions reduction by combustion air composition modification; 3) On-engine evaluation of NOx reduction catalysts; 4) Sensor research for NOx and particulates; and 5) Low-friction coatings for engine components.

11. Salvador Aceves, Lawrence Livermore National Laboratory (LLNL)

Engine Research at Lawrence Livermore National Laboratory

The LLNL is dedicated to defense research with annual operating and capital funds of $1 billion per year. LLNL’s strategy is to identify the intersection between lab core competencies, technology needs, and funding and believes in developing collaborative programs and strategic partnerships and integrating an internal program across directories. Numerous types of hydrocarbon kinetic systems are studied at LLNL. Diesel engines are unlikely to achieve the NOx and particulate matter levels required by legislation currently. The potentials of Homogenous Charge Compression Ignition (HCCI) Engines include high efficiency, very low NOx low cost, low cycle-to-cycle variation, fuel flexibility, and unthrottled operation. The technical challenges of HCCI engines are the difficulty to control, difficulty to start, high peak heat release and peak pressure, and high hydrocarbon and CO emissions. Three different HCCI experimental engines worked on by LLNL including the CFR engine, Volkswagen THI engine, and the Caterpillar 3401 engine. The accomplishments of the LLNL hydrocarbon sensors include dehydrogenation catalyst in combination with a proton-conducting electrolyte, demonstrated sensitivity to a variety of HCs with better than 25-ppm resolution, and durability and sensitivity verified by Ford. The Center for Fuels Assessment will develop a system-based framework that addresses the transportation fuel cycle. The vulnerability of ground water to fuel compounds that are emitted to the atmosphere was discussed and the concentration profiles of DBM, TGME, and MTBE in soil after one year of transport from a buried source were presented. Testing of plasma/catalyst processes on Cummins 100kW diesel engines showed using only 3% of the engine power output, the plasma increased the NOx reduction efficiency of a cheap catalyst by more than 2 times. Great reductions in NO and NO_2 occurred when testing with plasma-assisted catalyst. Other relevant LLNL engine technologies include magnetic bearings for turbochargers, isotopic tracing of fuel components, InVest: Integrated Vehicle Simulation Environment Test bed, femptosecond laser, and laser peening.

12. Ron Graves, *Oak Ridge National Laboratory*

Advanced Reciprocating Engine Technology at the Oak Ridge National Laboratory

The Advanced Propulsion Technology Center (APTC) is a comprehensive laboratory for internal combustion engines/powertrains. The APTC is designated as a DOE National User Facility where they can apply a number of unique or extraordinary diagnostic and analytical tools for engine/emission control R&D and conduct R&D from bench-scale to full system. Engine emissions projects at ORNL encompass multiple sponsors and partners. The basic tools for emission research at the ORNL have been well established with five dynamometer stands ranging from 25-400 horsepower, bench flow reactor for catalyst and sensor characterization, high-speed data acquisition, chassis dynamometer, emissions measuring equipment, and multiple methods for PM sizing and PM composition. ORNL staff takes expertise in emission measurements in general, PM measurement/characterizations, emission control engineering, exhaust speciation, vehicle-level chassis dyno experimentation, non-linear dynamics/real-time controls, electrical signature analysis, electrical machinery/power electronics, materials development and characterization, able to recognize and respond to industry needs. Advanced research tools emphasize faster response and more sensitivity. Emerging NOx sensors characterized in CRADA between Ford & ORNL include accomplishments of sensor response times determined as function of temperature for NOx and oxygen in bench rig, up to 400C, steady state pumping current values determined for NO and oxygen, current versus content curves were linear and corresponded well to values obtained by Ford, and the next effort is to measure sensor pumping currents under transient conditions. The “Zero” regulated emissions project at ORNL has integrated engine, after-treatment, and clean fuel with early results showing potential for major reductions in NOx and PM, yet highlight the daunting NOx challenge. Ultra-Lean Burn Natural Gas Engine for DOE ARES Program Integrate new technologies of new rotating spark increases probability of ignition, H_2 addition for combustion stabilization extends this lean limit, nonlinear controls, and demonstrate on existing system. The main reasons to add reformate gas are lean operation leads to combustion instability.

13. Bryan Willson, *Colorado State University, Fort Collins, CO*

State-of-the-Art Technologies for Stationary Natural Gas Engines

For 10 years, Colorado State University has been involved in retrofit industry research. Bryan presented numerous NOx emission rates from power generation options. From differing published sources there are 2,500-15,000 medium-speed natural gas engines and 2,600-16,000 medium-speed diesel engines in California that could be converted to natural gas using dual-fuel technology. The research focus has included enhanced mixing, NOx/HAPs research and advanced ignition systems. “Low Pressure” gas admission allows fuel injected late in scavenging, fuel injected at low pressure, poor air/fuel mixture with poor combustion and increased emissions. High-pressure injection produces dramatic reductions in NOx and fuel consumption. Research on commercialized systems includes the Engininuity/Woodward Governor HPFi System, the Hoerbiger/Altronic HYPERfuel System, the LCM Medium Pressure Fuel Injection System and the Dresser-Rand OptiJect Injector Insert. Current research on enhanced mixing has entailed experimental studies in optical engine (world’s largest) to study mixing and validating CFD models, and also CFD to model and optimizing mixing from fuel delivery systems. Current research on natural gas engines cover low NOx combustion, NO_2 formation in low-NOx engines, precombustion chamber NOx formation, and hazardous air pollutants (HAPs). Research on HAPs is in the following areas: Formaldehyde formation mechanisms, engine studies, mitigation studies, legislative support to EPA and catalyst studies. Ignition studies have been on conventional, micro-pilot, and advanced ignition systems. The research needs for the ARICE program proposed by Colorado State University include the following: 1) Advanced natural gas engine concepts being pursued by the ARES program; 2) DOE funding university research on ignition and friction reduction for advanced natural gas engines; 3) Precompetitive research needed on oxidation catalysts and SCR systems for natural gas and diesel engines; and 4) Significant research needs on dual-fuel engine conversions to convert diesel engines to natural gas operation.

14. Robert Dibble, Solo Energy Inc, Alameda CA

Needs of a New Distributed Generation Power Company

In switching hats, Robert took on the role of the consumer. Trying to be a power company, Solo Energy deliver services, not boxes. The customer-focused solutions are no up-front investment, no technical risk, predictable, fixed rate pricing, no fuel risk, and included installation and maintenance. The reasons being cost, price, volatility, and reliability. There are needs of a distributed generation power company. Visiting machines for overhaul and maintenance is very expensive and overhauls need to be reduced. The goals of the ARICE program are reachable.

15. Don Teixeira, *CEC / University of California*

Initial Development of Base-line Emission Factors and Near-term Mitigation Techniques

Phase I, near completion, developed a comprehensive statewide BUGs (Back-Up Generators) database (excluding the Bay Area). The contractor for the project was the Center for Environmental Research and Technology of UC Riverside. Currently, the final work scope is being developed in co-ordination with the ARB, other air regulatory groups and the Industry Advisory Group. In the Air Emissions Mitigation, measurement procedures and protocols are being evaluated, representative population of engines to test is being selected, baseline (uncontrolled) emission factors for stationary engine operating modes are being established, and near term air emission mitigation techniques of alternative (cleaner burning) fuels and emissions control hardware are being tested.

16. Shuh-Haw Sheen, *Argonne National Laboratory (ANL)*

Advanced Sensors for Real-time Control of Advanced Natural Gas Reciprocating Engine Combustion

ANL works on practical sensors for RICE systems, and advanced sensors for real time control of advanced natural gas reciprocating engine combustion. ANL is one of DOE's largest research facilities operated by the University of Chicago. The ARES program goal includes developing cleaner and more efficient next generation natural gas engines that will increase fuel combustion efficiency, reduce emissions of NOx, hydrocarbons, air toxics, and greenhouse gases, and reduce system costs and maintenance frequency. The project objectives for ANL in the ARES program are to develop advanced sensors for real- time combustion monitoring of advanced natural gas reciprocating engines, including the proposed sensors for NOx emission and natural gas composition. The technical approaches taken by ANL include NOx sensors based on ion-mobility spectrometry and fuel composition sensors based on acoustic techniques, measurements of speed-of-sound, attenuation, and acoustic relaxation spectroscopy. Special features for the speed-of-sound sensor include 1) Pulse-echo measurement; 2) Narrow flow channel design; 3) Higher-order echo analysis; 4) 0.5 MHz center frequency; and 5) Dual cavity design. Sheen presented further detail with graphical slide presentations on the testing of these two sensor projects.

Panel IV Private R&D, Fuels, Exhaust Treatment

17. James Paul, Ricardo, Inc.

Emissions and Efficiency Targets: Advanced Technology Reciprocating Internal Combustion Engines

Ricardo has conducted an internally funded research project to define future engine technologies. This is the most comprehensive evaluation of future technologies ever carried out by Ricardo. It is the collective view of technical specialists from Ricardo worldwide. Given the particulate levels as well as political pressure, it can be assumed that the use of particulate filters will have a very high probability. A form of NOx after-treatment will probably be necessary. Current development programs of heavy-duty diesel manufacturers include Cummins, Navistar, Detroit Diesel and other manufacturers. Emissions technology is driven primarily by Federal, State and Local legislation and includes both combustion modifications and aftertreatment systems. Current technology will allow attainment of ARB and EPA Tier 2 and Tier 3 limits. Popular technologies to reduce emissions will be 1) Advanced fuel injection and combustion chamber design; 2) Advanced aftertreatment - PM traps, SCR, NO_x absorber, oxidation catalysts; 3) Integrated system control strategies; and 4) EGR (including cooled EGR). Improved diesel engines have thermal efficiencies approaching those of fuel cells. Fuel efficiency improvements of over 20% are expected during the next 10 years. Popular technologies to improve efficiencies will be 1) Advanced Fuel Injection and combustion chamber design; 2) Improved Electronic Controls; 3) Variable valve timing, electronic valve actuation; 4) Integrated system control strategies; and 5) Turbocharger improvements. Significant changes in the internal combustion engine over the next decade will impact strongly on fuel and lubricant requirements especially low sulfur fuel and lubricant effects on emissions. Beyond 2010, the challenge will continue with alternative fuels and new combustion technologies.

18. James J. Cole, Southwest Research Institute (SWRI)

Advanced Reciprocating Engine Technology for California's Distributed Generation

SWRI was involved in the initial investigating of the technologies for the ARES Program. The funded tasks of the ARES program covered the technical path evaluation, knock modeling, high BMEP engine development, and exhaust after-treatment. The areas not funded in the ARES Program were HCCI, HPDI, sparkplug life, laser ignition and sensors. The details of ARES were proprietary. ARES along with ARICE will produce clean power generating products that enhance the public good and make economic sense. NOx reduction technology comparison includes durability, efficiency, and cost. Non-traditional approaches and absolutely necessary advanced controls will be the key in obtaining the proposed ARICE technologies.

19. Chuck LeTavec, *BP Amoco*

ARCO EC Diesel Program Update

EC Diesel Demonstration Program Deliverables include emission data (reduction from fuel change and passive regenerating particulate filters), toxic, speciation and sizing data (with and without catalyst), and durability information (low sulfur/aromatic high cetane fuel and passive regenerating particulate filters). Participants involved were National Agencies, California Agencies, Academia, Industry, and Fleet operators. Tables of fuel analysis reports, average refuse hauler emissions, school bus emissions, tanker truck emissions, and grocery trucks emissions were graphically displayed for comparison data. First round emission testing illustrate PM, HC & CO reduced >90%, the second round emission testing completing showed preliminary results of >90% PM, HC reductions and toxics and speciation samples collected after one year of operation samples at DRI for analysis.

20. Osama Ibrahim, *Rypos, Inc.*

Active Diesel Exhaust Particulate Trap for Diesel Engines

Osama introduced the issue of passive versus active diesel exhaust particulate traps for diesel engines. The RYPOS traps include the: 1) BEKAERT Filter Module; 2) Filter Cartridge Design; 3) Filter housing; and 4) Electronic control. Under the passive traps include the catalyzed ceramic filters with ceramic cells, oxidation catalyst for regeneration, and precious metals. For the active traps, the unique characteristics of BEKAERT and filter module are utilized. The Rypos trap was explained through a diagram with control circuitry, power source, filter housing, clean exhaust and dirty exhaust. The Regeneration Test involves pressure versus time. The Rypos trap has competitive advantages and the market opportunity includes OEM and retrofit capabilities. Rypos believes it has a product of high performance, energy efficiency, fully automatic, rugged, adaptive to 50kW-1000kW diesel generators, wide application, and can be used with or without diesel oxidation catalysts.

21. Paul Miles, Sandia National Laboratory (SNL)

Combustion Research Facility (CRF)

At the Combustion Research Facility, the key is providing detailed understanding, selling knowledge, working with multiple partnerships, and dealing in a narrow portfolio (optical diagnostic techniques). Customers have access to unparalleled breadth and sophistication of facilities and diagnostics of programs at CRF: exhaust gas recirculation, high-speed direct injection diesel, port fuel injection, alternative fuels, diesel simulation facility, heavy-duty diesel engine, gasoline direct injection (side injection), particulate matter diagnostics, and the hydrogen lean burn engine program. CRF's approach is to assemble experimental hardware that mimics realistic engine geometry while providing optical access. Optical access is obtained through periscopes in an exhaust valve or through quartz windows in piston crowns, spacer plates and quartz cylinder liners. CRF is working in partnership with engine manufacturers to enable more fuel efficient, cleaner burning engines.

Lunch Break 1:00 PM – 2:15 PM

2:15 PM – 4:30 PM Discussion Topics

The afternoon session began with Avtar Bining's opening remarks about the morning session of presentations current status of technology and the next steps. The Core Group will be solely from the public organizations to avoid conflicts of interest in the decision-making processes and subsequent funding of projects of the ARICE Program. The Advisory Committees can be set up in two ways. The first way would be according to the nature of the organizations being represented, and the second way would be to set up the committees by the specific tasks at hand. The Core Group and Advisory Committees can not travel frequently, but communication through telephone, conference call and email is strongly encouraged. The ARICE Program is on a strict schedule. The ARES Program was specifically for natural gas engines, and the ARICE Program is more flexible, more open to opportunities, with cleaner fuels, any advanced technology on engine hardware or software, and post combustion treatment. The first objective will be engine cleanup and then exhaust treatment.

Will the ARICE program include any fuel combination?

ARICE will be flexible with any component of the system; it will be an open arena. All fuels should be included – diesel, natural gas, bio fuels, clean fuels (which could be less expensive in the future), gas-to-liquid and others.

What will be the funding of the program? How much will be available? How many projects?

The funding is undecided at the moment. This will be determined after today's ARICE workshop has adjourned and all the notes and proceedings are tied together and then reviewed. The ARICE Program needs and targets will be looked at, and then the determination will occur regarding what is needed to reach these proposed targets.

How will the program be prioritized? What will be the focus? Will there be a more balanced focus? How broad? How much money? Will ARICE include new and/or existing engines?

The California Energy Commission will see how the industry responds to the solicitation. ARICE is open to both new and existing engines because the needed move is to further the advanced technology of these ARICE systems including retrofitting of existing systems. The CEC has been doing some work with retrofit engines already. The technology acceptable today might not be accepted 5 years down the road. The ARICE Program wants to make sure the technology is current and will be accepted. Also, the existing engines need to be looked at to see if it would make more economical sense just to terminate them than to retrofit them.

Will ARICE be based on results of existing projects?

More exploration on past and existing projects will be done and then looked at to furthering R&D on these projects.

Will the ARICE Program be complimentary to the ARES Program? What are ideas on how to coordinate the ARICE and the ARES Programs?

Yes very much so, and vice versa. To coordinate the two programs, the ARICE Program will use the results from the ARES Program and integrate them into the ARICE Program. As time moves forward, the ARICE Program and participants will see more and more how to coordinate the two programs. If there are gaps to fill in the ARES Program, the ARICE Program will try to fill these holes. The ARICE Program would like to use the results from the ARES Program.

What would be the management structure of the ARES and ARICE Programs meshing together?

Initially, the ARICE management structure would not be with the ARES Program, but would slowly coordinate with the ARES Program. The coordination of the two programs is welcomed. The meshing together will also make certain no work is duplicated between the two programs. The results from the ARES Program show after-treatment is definitely needed to reach the proposed goals.

What after-treatment will be needed? What about a reverse approach looking at after-treatment through the back end? If there is the advance in the after-treatment, then you would afterwards look into the engine? Actually making the engine cheaper?

Initially, this approach is more for retrofitting, but the advanced after-treatment technologies can then also be applied to new engine approaches. After-treatment is for retrofitting of existing engines. In the ARICE Program, the engine and exhaust after-treatment should be looked at as a whole system, as one entity. The components of the ARICE systems should be the engine, aftertreatment, and third being the fuel forming the complete system.

The ARES Program has a 10-year goal. What is the driving force behind the ARICE Program? How will the goals be met for the ARICE Program?

Blackouts became news last year along with engines being used to produce power and concerns about air pollution/emission. California's problem was already *yesterday*, and needs to take advantage of ARICE systems *now*. A much shorter turn around is needed than the ARES Program; the ARICE Program needs to move faster because of California's emergency. The ARICE Program needs to be more aggressive. The industry can also take advantage of the current situation by getting their products on the market. The ARICE Program will set goals according to Department of Energy (DOE) and the Air Resources Board (ARB).

Comment from **Dan Spear,** ***San Diego APCD***: With regard to getting engine permits for 1 g and 0.1 g emissions, 0.1 g is easier to obtain the permit for. The risk criterion goes down from 10 in a million with 1 g to 1 in a million with 0.1-g emissions.

As a manufacturer of SCR, what should Miratech do? Contact engine manufacturer? Or CEC?

Both, the information should be exchanged. Engine manufacturers may also be interested in after-treatment. CEC does not fund projects on a one-to-one basis; the interested parties need to go through the solicitation process.

As a distribution utility looking at electrical power output, lb/MWh is used. What are the common units for the engine? And for the generator? Can a common unit be applied to the ARICE Program?

ARB is using lb/MWh for Distributed Generation standards. Distributed generation technology uses lb/MWh, and engines use g/bhp-hr. Discrepancies will follow if different efficiencies for the generator are used; different generators do not have the same efficiency. Both units will need to be used initially, but ultimately for the distributed technologies, lb/MWh will be used. Not all applications and proposals will be for power generation, some will be for shaft power applications only, and these will not have lb/MWh (electric) units but will use g/bhp-h units.

What kind of team will be formed? Who will be the focal point?

To start, the focal point will be the California Energy Commission since it has taken the lead so far, and in the future we will have to see how to manage the California ARICE Collaborative.

Will the reciprocating engines be compared to other technologies (like fuel cells and gas turbines)?

The Distributed Generation Group of the Air Resources Board (ARB) is already evaluating various DG technologies. They are compiling data on all distributed generation technologies and comparisons are being made.

Will there be truck-mounted mobile generators? If there is a power supply crisis, what is available? i.e. is power barge available?

Caterpillar has 240 MW portable rental modules. The power barge is a specific question/concern to the manufacturer. A power barge would not be environmentally acceptable in California; this is a project specific question.

Targets for California?

There is the ability to get to 0.5 g/bhp-hr engine, but only at 33% efficiency. Have to use 3 way catalysts, after-treatment, etc. The ARICE goals are very aggressive. The time frame is the major difference between the ARES and ARICE Programs. The need is to clean up the exhaust.

Efficiency vs. Emissions? Priorities?

Treating the exhaust is more near term; the efficiency advancements can be put off in the beginning by accepting current state of the art efficiency level to reach the emission goals.

How can we initiate the ARICE Program? Time frame?

22. **Gordon Gerber** of **Caterpillar** presented the proposed plan by the ARES Consortium for the ARICE Program. According to the ARES Consortium, the ARICE Program needs to be a multiyear cooperative agreement between the CEC and Industry, in coordination with the DOE - ARES Program, to develop ultra low emissions capability on current and upcoming reciprocating engines (natural gas, diesel, bio-fuels).
    - Two Phases, 2002-03 and 2003-04
    - Coordination with DOE ARES Program
    - Partnerships with Nat. Labs / Universities
    - Focus on **Fast Emissions Reduction**
    - RFP's Announced September 2001
    - Contracts Signed January 2002
    - Phase 1 Complete 2002-3 (0.1 g NOx)
    - Phase 2 Complete 2003-4 (0.05 g NOx)
    - CEC FY2002 Funding $15M

The best solution for the success of the ARICE Program will be a coordinated effort from the reciprocating engine Industry, the ARES Program, and the newly formed ARICE Program all working cohesively with the national labs, universities, research institutes, local agencies, end users, and suppliers. Due to California's needs, the ARICE Program is asking of technologies coming to market in a faster time period and obtaining quicker program results. The ARICE program should be a two-phase program from 2001 to 2004 given the current emissions at 2 g NOx. Phase I will be 0.1 g NOx demonstrations in 2002 and Phase II will be 0.05 g NOx demonstrations in 2003.

How can public be sure their short term needs can be satisfied when the manufacturer's have focused on long term goals in the past? History of industry has been long term, how can they change top short term?

The ARICE Program will have to measure specific goals by performance targets. The industry has changed plans due to the needs of California. The efficiency is not the critical issue at the present time, the concern is over the emissions and the efficiency can be whatever it can be at the current level.

Will the ARICE Program be more focused on selling new products or retrofitting old systems?

There are large numbers of engines that are sitting around. Retrofitting can make them run cleaner. There is a fleet of engines that could use aftert-treatment. The solicitation is not only for engine manufacturers, but also for all components of engine systems including after-treatment. The ARICE Program will also look into retrofitting. Equal opportunity will be given to the technologies and technical developments. The ultimate goals are to lower NOx emissions and increase the efficiencies.

What is the issue of the industry's Short-term vs. Long-term plans?

The DOE asked the ARES Program for a high-risk long-term plan accounting for 1) Efficiency; 2) Emissions; and 3) Cost. This is where some of the confusion has come from when the industry has been thought of as having long term goals.

Does the ARICE Program want to include replacement of older engines with new engines?

The ARICE Program is for the technology advancement.

Are there in-use compliance emissions standards for stationary engines as there are currently for mobile engines?

Have to sell power modules, have to exceed TIER 1, right now at 6.9 g/bhp-hr (diesel). Nothing is in place right now with 0.1 g/bhp-hr. There is some in-use compliance standards for the in-use emissions, after certification for stationary engines.

If the industry has already brought NOx emissions down from 10 g to 1.5 g, is it cost effective to bring the emissions down from 1.5 g to 1.0 g or even 0.5g? The incremental reduction is small, but cost effective? The emissions have to get lower than the standard, that is why 0.5 g is being questioned.

Can anything meet the standards? Is it too expensive? What about the challenge of the micro-turbine to the ARICE systems?

The engine is not for today. California needs this engine for tomorrow, next year, and the year after. Is the engine a workhorse or a show-horse? The diesel and natural gas engine are the workhorse and the other technologies (fuel cells, micro-turbines, etc.) will remain show horses until the next term. Distributed generation technologies can be independent of the grid. Other countries are looking for distributed generation. They do not have the money for a grid system. Remember that if the engine sells in California, it will sell anywhere in the U.S and perhaps even abroad. There are other solutions on the horizon, so if the engine manufacturers and industry partners want to be in business, they need to meet the proposed standards to stay competitive with new emerging technologies in the future.

Regarding the time frame, is the industry ready? What is the time frame for the ARICE Program?

What is the program structure? 2-3 year time frame? Existing technologies? Legitimate role for the universities?

The emissions side is a little clearer. The catalyst work is clearer. **Isolation is not part of the plan.** DOE reviewed 33 technologies during the visits to the National Labs. The ARES Program only goes through 2006.

What will be the various roles in the collaborative?

It is a collaborative effort with specific roles and responsibilities for and commitments by all parties involved including regulatory agencies. These roles will become more clear as we put together various committees.

As a bidder, private industry, caution role, what it the proprietary role? If a project is awarded as a system, how does cost sharing work? How does the intellectual property share?

In the past, 50% of funds were to be matched. Now the match funds are a part of the evaluation criteria. The proposal will not be rejected merely due to the lack of match funds.

Some of the terms and conditions in solicitation?

Negotiations will occur at contract signing stages. Intellectual property stays with the private company, not with the State of California. CEC usually asks for 1.5% royalty or repayment of double the funding amount. CEC does not want the contract funds to be used to buy the equipment. For testing purposes, extra time may be needed and usually the equipment purchased using CEC contract funds will remain with the private companies. More details will be provided in the solicitation.

What is the availability of low sulfur diesel fuel?

Air Resources Board is working on implementation of the low sulfur diesel program.

As the program coordinator, these types of programs usually border on over communicating, at least in the beginning. May be tiring, but is for the overall benefit in the long run.

To summarize the workshop discussion, the following were discussed:

1) ARES + ARICE
2) Coordination
3) Integration
4) Interest

Bud Beebe mentioned, there's a challenge… there's more. What are the requirements right now for reciprocating engines? They will become more stringent in the near future. **What can we do to stay ahead of the curve?** Timely curve? Will it be cost effective? It's not an easy task, the California Energy Commission does not have all the answers, that's why everyone present at the workshop has attended.

General consensus is:

- Industry is very willing to work in/with the ARICE Collaborative for meeting aggressive emission reduction (to <0.1 g/bhp-hr NOx) and efficiency improvement (10-20 percent over the current) goals with flexibility to choose engine system (fuel, engine, exhaust treatment etc.) technologies to make it happen, and these goals are reachable in the near-term (3-5 years).

- To achieve low NOx (0.1g/bhp-hr and less), exhaust treatment technologies (SCR etc.) are needed and this will require low-sulfur fuels also for SCRs to work efficiently and cost-effectively!

- Synergy among different R&D programs (such as public and private, stationary and mobile etc.) would be very beneficial to reap maximum results/benefits and avoid duplication.

- A collective effort from public organizations (fed, state, and local), engine manufacturers, national labs, universities/academia, private R&D industry, emission control manufacturers, fuel producers/suppliers, utilities, users, and environmentalists is needed to reach at our common goal of providing efficient, affordable, clean, reliable and sustainable distributed generation (electricity supply) in California.